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Alpha Irradiation Modeling

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Introduction

With the end of the Cold War and the associated limitations imposed on the nuclear weapons stockpile by strategic arms treaties, much has changed in the stockpile stewardship program. Weapons that were originally designed for stockpile lives on the order of 15 to 20 years are now being evaluated for much longer periods: in some cases as much as 60 years. As such, issues that were once considered to be of no consequence are being reexamined. Among these is the extent of the radiation dose received by secondary organics over time that results from the intrinsic alpha source of the weapon components.

This report describes the results of work performed to estimate the alpha radiation deposition in the organic components of an LLNL system at specific points in its stockpile life. Included are discussions of the development of the intrinsic time- and energy-dependent alpha source term per unit mass, estimation of the effective source and absorber material thicknesses, development of a simplified model for the total intrinsic alpha source term and energy deposition in the absorber, and the alpha radiation deposition in the organic components of a selected LLNL weapon.

Intrinsic Alpha Source Term Per Unit Mass

Intrinsic parent and daughter time-dependent mass resulting from the decay of actinide isotopes were calculated on the basis of 1 g of initial parent inventory with ORIGEN-S (ORNL-CCC-545) for decay periods of 1 to 60 years. Results from the ORIGEN-S calculations were then imported into EXCEL spreadsheets and combined with the appropriate parent isotope specific activities (Ci/g), absolute alpha particle intensities (%), and alpha particle energies (keV) (Browne and Firestone 1986) to produce the alpha particle and energy spectra per unit time per unit mass of the parent (alphas/s-g and keV/s-g). Import of this information into additional EXCEL spreadsheets allowed calculation of the source alpha particle and energy spectra (the suite of potential alpha particles in the range of 3720 to 10548.7 keV) for any isotopic mix of actinide parents through a simple change in the composition table. The source alpha particle and energy spectra were calculated at specific periods in time in two ways: time-integrated and time-product decay. Time-integrated source spectra were determined by trapezoidal rule integration of annual decay sources through the time period of interest; time-product source spectra were determined by the product of the annual decay source at the time period of interest and the time period of interest.

Effective Source and Absorber Material Thicknesses

In the energy range of 3000 to 12000 keV, the logarithmic-logarithmic plot of mean alpha particle depth (cm) versus alpha energy (keV) exhibits a linear relationship for a broad range of elements (Littmark and Ziegler 1980). As such, linear regression analyses of the natural logarithm (ln) of the mean alpha particle depth (cm) versus the ln of the alpha energy (keV) were used to estimate the mean alpha particle depth for the suite of alpha particle energies in the intrinsic alpha source term. To cover as broad a range of potential material constituents as possible for both the source and absorber, the elements hydrogen (Z=1) through neon (Z=10), magnesium (Z=12), aluminum (Z=13), silicon (Z=14), uranium (Z=92), and plutonium (Z=94), as both alpha- and delta-phase, were included. In the case of plutonium, its inclusion was accomplished through a density ratio adjustment to the uranium mean alpha particle depth data. Results of these linear regression analyses were then imported into EXCEL spreadsheets to allow calculation of the mean alpha particle depth in a single or composite material as a function of the alpha energy.

The effective source and absorber material thicknesses were defined as the source-weighted mean alpha particle depth in the material. For the purposes of these calculations, 1 g of source material was assumed.

Simplified Model for the Total Intrinsic Alpha Source Term and Energy Deposition in the Absorber

To determine the total source energy emitted, a source mass is calculated assuming the material is spherical in shape, has a radial thickness equal to the effective source material thickness, and a radius that is appropriate for the source to absorber material interface.

In addition to the effective absorber material thickness, the number of mean alpha particle depths in the absorber material and the absorption potential of the absorber material (i.e., the fraction of the incident source energy that can be absorbed in the number of mean alpha particle depths) are based on the source-weighted mean alpha particle depth in the material. By definition, the number of mean alpha particle depths in the absorber material, $NMAPD_a$, and the absorption potential of the absorber, AP_a, are given by

$$NMAPD_a = T_a/MAPD_a \tag{1}$$

$$AP_a = [1 - 0.5^{NMAPD_a}] \tag{2}$$

where

T_a = thickness of absorber material a (cm) and
$MAPD_a$ = mean alpha particle depth in absorber material a (cm).

The total source energy absorbed is derived from the product of the total source energy emitted, the absorption potential of the absorber, and the fraction of the total source energy emitted that is incident on the absorber. The fraction of the total source energy emitted that is incident on the absorber is calculated for three incident source energy conditions: maximum, average (best estimate), and minimum. The maximum incident source fraction, ISF_{max}, is defined by the source originating from the mass of material within the spherical shell that lies between the surface and a depth equivalent to one-tenth the effective source material thickness, corrected for an appropriate solid angle of emission. It is given by

$$ISF_{max} = \left(\frac{1}{180°}\right)\cos^{-1}(0.1) \tag{3}$$

where

$\cos^{-1}$ = is expressed in degrees.

The average (best estimate) incident source fraction, ISF_{avg}, is defined by the average source originating from the mass of material within ten spherical shells that lie between the surface and incrementally increasing depths that vary between one-tenth and one times the effective source material thickness, corrected for their appropriate solid angle of emission. It is given by

$$ISF_{avg} = \frac{\left(\frac{1}{180^\circ}\right)\sum_{i=1}^{10}\cos^{-1}(i)(0.1)}{10} \tag{4}$$

The minimum incident source fraction, ISF_{min}, is defined by the source originating from the source mass, corrected for the appropriate solid angle of emission. It is given by

$$ISF_{min} = \left(\frac{1}{4\pi}\right) = 0.0796 \tag{5}$$

Deposition Calculation Results

Alpha radiation deposition results will be provided for a typical system secondary during the conference presentation.

References

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